Coral thermal microclimate: Investigating the effects of irradiance, flow and coral thermophysical properties

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Certificate

I certify that this thesis has not already been submitted for any degree and is not being submitted as part of candidature for any other degree.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. All information sources and literature used are indicated in the thesis.

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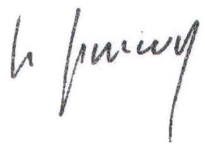

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Abstract

Understanding the processes that drive the variability in thermal tolerance among scleractinian corals is key to predicting the impacts of rising worldwide temperatures on coral reefs. This thesis explores the thermal microclimate of corals, and specifically examines the thermal effects of environmental conditions of flow and irradiance, combined with the optical, thermal and morphological characteristics of individual coral colonies.

The temperature of branching (*Porites cylindrica*) and hemispherical (*Porites lobata* and *Cyphastrea serailia*) coral species was monitored on a shallow reef flat in the Southern Great Barrier Reef. This revealed a strong diurnal and tidal pattern in solar heating of corals, whereby maximum coral surface warming of $\sim$+0.6 °C occurred during low Spring tides, under conditions of high irradiance and low water flow.

Microsensor temperature measurements were used to demonstrate for the first time that at flow velocities < 5 cm s^{-1} heat transfer at the surface of corals was controlled by a thermal boundary layer (TBL). Dimensionless analysis of heat transfer (Nusselt-Reynolds number plots) confirmed that convective heat transfer at the surface of hemispherical *Porites lobata* and branching colonies (*Stylophora pistillata* occurred through a laminar boundary layer, consistent with predictions from engineering theory for simple geometrical objects. For topographically more complex corals (*Favia* and *Platygyra* sp.) both the TBL thickness and the surface temperature was spatially heterogeneous.

Temperature and spectral reflectance measurements were used to investigate close links between the thermal and optical properties of corals. Coral surface temperature could be expressed as a linear function of the tissue's absorptivity, but this relationship was species-specific, and highlighted the thermal importance of the skeleton. The spectral composition of light was important in determining the magnitude of coral surface warming, and short wavelengths (<500 nm) had the greatest heating efficiency.

Finally, a mechanistic thermal model of corals identified both irradiance absorption and convective heat loss as the major controlling parameters of coral surface warming. Conductive heat transfer into the skeleton was a negligible portion of the overall heat budget, except for small coral diameters ($\sim$ 1 cm). Experimental and theoretical results throughout this thesis revealed that the surface warming of hemispherical coral species

was greater than that of branching species, and indicates that massive species may tolerate temperatures greater than previously thought. In light of the greater bleaching resistance of massive compared to branching species, this warrants further investigation into the effects of small temperature differences on the physiological response of morphologically distinct, bleaching sensitive and resistant coral species.

Table 1: List of terms.

α	Tissue absorptivity
δ	Boundary layer thickness (μm or mm)
ϵ	Surface emissivity
ρ	Density ($kg\ m^{-3}$)
σ	Stefan-Boltzmann constant (5.673 x $10^{-8}\ Wm^{-2}K^{-1}$)
τ	Transient response time (s)
ΔT	Warming: $T - T_{water}$ (K or C)
$\Delta T_{m\ tissue}$	Maximum surface warming (K or C)
$\Delta T_{m\ skel}$	Maximum skeleton warming (K or C)
$\Delta F/F_m{}'$	Effective quantum yield of PSII
κ	Skeleton thermal diffusivity ($m^2 s^{-1}$)
ν	Water kinematic viscosity ($m^2 s^{-1}$)
ANOVA	Analysis of Variance
A_1	Surface area of sun-exposed tissue (m^2)
A_2	Surface area of shaded tissue (m^2)
A	Total coral surface area (m^2)
Bi	Biot number
c	Skeleton specific heat capacity ($Jkg^{-1}K^{-1}$)
DBL	Diffusive boundary layer
E	Incident irradiance (Wm^{-2})
F	Variable chlorophyll a fluorescence
$F_m{}'$	Maximum fluorescence in light
F_v/F_m	Dark adapted maximum quantum yield of PSII
h	Convection coefficient ($Wm^{-2}K^{-1}$)
k	Conductivity ($Wm^{-2}K^{-1}$)
K	Skeleton conductance ($Wm^{-2}K^{-1}$)
Le	Lewis number
Nu	Nusselt number
PAR	Photosynthetically active radiation
PSII	Photosystem II
q_{rad}	Absorbed radiation flux (Wm^{-2})
q_{cond}	Conduction flux from the tissue to the skeleton (Wm^{-2})
$q_{conv\ 1}$	Convection flux from the tissue to the water (Wm^{-2})
$q_{conv\ 2}$	Convection flux from the skeleton to the water (Wm^{-2})
Re	Reynolds number
Sh	Sherwood number
TBL	Thermal boundary layer
T_{tissue}	Tissue temperature (K)
T_{skel}	Skeleton temperature (K)
T_{water}	Water temperature (K)